D E C L A R A T I O N

I, YUZURU OKABE, a Japanese Patent Attorney registered No. 9411, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan do solemnly and sincerely declare that I well understand the Japanese language and English language and the attached English version is full, true and faithful translation of the Japanese Patent Application No. 3-343601 filed on December 25, 1991 in the name of NIKON CORPORATION.

And I made this solemn declaration conscientiously believing the same to be true.

I hereby declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 3rd day of August, 2001

YUZURU OKABE

PATENT OFFICE
JAPANESE PATENT APPLICATION

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[Title of the Invention]	PROJECTION EXPOSURE APPARATUS
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[Material]	Specification	1
[Material]	Drawings	1
[Material]	Abstract	1

[Proof Requirement] Yes

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[Title of the Invention] Projection Exposure Apparatus

[What is claimed is:]

[Claim 1] A projection exposure apparatus for projection-exposing a pattern on a projection negative by means of exposure light from an illuminating optical system through a projection optical system, wherein

said illuminating optical system includes light source means for supplying exposure light, annular light source forming means for forming an annular secondary light source by the light from said light source means, and condenser lens for condensing the light beam from said annular light source forming means on said projection negative; and

said apparatus satisfies the following condition:

$1/3 \leqq d_1/d_2 \leqq 2/3$,

where d_1 is the inner diameter of said annular secondary light source, and d_2 is the outer diameter of said annular secondary light source.

[Claim 2] A projection exposure apparatus according to Claim 1, satisfying the following condition:

$0.45 \leqq NA_2/NA_1 \leqq 0.8$,

where NA_1 is the numerical aperture of said projection optical means on the projection negative side, and NA_2 is the numerical aperture of said illuminating optical system determined by the outer diameter of said annular secondary light source.

[Detailed description of the Invention]

[0001]

[Field of the Industrial Utilization]

This invention relates to a projection exposure apparatus for projection-exposing minute patterns necessary for the manufacture of semiconductive integrated circuits or the like onto a substrate (wafer).

[0002]

[Prior Art]

As a prior-art projection exposure apparatus, there is known one in which exposure light is applied to a projection negative such as a mask or a reticle (hereinafter referred to as the reticle) on which a circuit pattern is formed, and the image of the circuit pattern on the reticle is transferred onto a substrate such as a wafer (hereinafter referred to as the wafer) through a projection optical system.

[0003]

Here, resolving power reticle transferred onto the wafer is theoretically of the order of 0.5 x λ x NA when the wavelength of the exposure light is λ and the numerical aperture of the projection optical system is NA.

In the actual lithography process, however, a certain degree of depth of focus becomes necessary due to the influence of the curvature of the wafer, the level difference of the wafer by the process, etc. or the thickness of photoresist itself. Therefore, practical

resolving power to which a factor such as the depth of focus has been added is expressed as k x λ x NA, where is called a process coefficient and is usually of the order of 0.7 - 0.8.

[0004]

[Problems to be solved by the Invention]

Now, in recent years, particularly the tendency toward the minuteness of patterns transferred onto wafers is advancing and as a technique for coping with this tendency toward the minuteness, it is conceivable to shorten the wavelength of exposure light or to increase the numerical aperture NA of the projection optical system, as is apparent from the above-expression of the resolving power.

[0005]

However, in the technique of shortening the wavelength of exposure light, glass materials usable for the lenses of the projection optical system become limited with the shortening of the exposure light, and it is difficult to design a projection optical system in which aberrations have been sufficiently corrected, in such limited glass materials.

Also, in the technique of increasing the numerical aperture NA of the projection optical system, an improvement in resolving power can be surely achieved, but the depth of focus of the projection optical system is inversely proportional to the square of the numerical aperture NA of the projection optical system. Accordingly,

the depth of focus decreases remarkably, and this is not preferable. Moreover, it is difficult to design a projection optical system which has a great numerical aperture NA and yet in which aberrations have been sufficiently corrected.

[0006]

Considering the above-mentioned circumstances, it is an object of the present invention to provide a projection exposure apparatus in which the depth of focus of a projection optical system is improved, whereby in practical use, a circuit pattern on a reticle can be faithfully transferred onto a wafer with a higher resolution.

[0007]

[Means for solving the Problems]

To achieve the above object, a projection exposure apparatus according to the present invention for projection-exposing a pattern on a reticle through the projection optical means onto a substrate includes, as shown in Figure 1, for example, light source means (1, 2, 3, 4) for supplying exposure light, annular light source forming means (5, 6) for forming an annular secondary light source by the light from said light source means (1, 2, 3, 4), and condenser lens (7) for condensing the light beam from said annular light source forming means (5,6) on the projection negative, and is designed to satisfy the following condition:

[0008]

$1/3 \leq d_1/d_2 \leq 2/3$,

where d_1 is the inner diameter of the annular secondary light source, and d_2 is the outer diameter of the annular secondary light source. Then, in accordance with the above-mentioned basic configuration, it is desirable that when the projection negative (reticle) side numerical aperture of the projection optical system is NA_1 and the numerical aperture of the illuminating optical system determined by the outer diameter of the annular secondary light source is NA_2, the projection exposure apparatus according to the present invention be designed to the following conditional expression:

$0.45 \leq NA_2/NA_1 \leq 0.8$

[0009]

[Operation of the Invention]

The projection exposure apparatus according to the present invention is designed to illuminate the reticle by the exposure light from the annular plane light source, i.e., effect so-called annular illumination (or inclined illumination).

At this time, the annular secondary light source is designed to satisfy the following conditional expression (1), whereby the depth of focus of projection optical system can be improved to achieve an improvement in practical resolution.

$1/3 \leq d_1/d_2 \leq 2/3$ ..... (1)

where d_1 is the inner diameter of the annular

secondary light source, and d_2 is the outer diameter of the annular secondary light source.

[0010]

Specifically, according to the present invention, it becomes possible to improve the process coefficient, which has an important effect upon the practical minimum resolved line width as mentioned above, to the order of 0.5.

When as an example, the wavelength λ of light source is i-lime (365nm) and the wafer side numerical aperture NA of a projection lens is 0.4, the line width which can be resolved by a prior-art exposure apparatus in which the process coefficient is 0.7 is of the order of 0.64 μm from k x λ/NA, while in the exposure apparatus according to the present invention, the process coefficient k is of the order of 0.5 and therefore, the line width which can be resolved is 0.46 μm. Thus, it will be seen that in the projection exposure apparatus according to the present invention, an improvement in resolution after a practically more sufficient depth of focus than in the prior-art apparatus has been secured is achieved.

[0011]

Here, if the lower limit of this conditional expression (1) is exceeded, the inner diameter of the annular light source becomes too small to reduce the effect of the annular illumination of the present invention, whereby it becomes difficult to improve the depth of focus and the resolving power of the projection optical system.

On the other hand, if the upper limit of the conditional expression (1) is exceeded, a pattern of the same line width on the reticle is transferred to have a varied line width on the wafer depending on its periodicity, whereby the reticle pattern can not be transferred on the wafer faithfully. Moreover, it becomes difficult to form a desired line width pattern on the wafer since an amount of variation of the line width becomes large with respect to variation of the exposure amount.

[0012]

Further, to sufficiently bring out the effect of annular illumination according to the present invention, it is desirable that when the projection negative side numerical aperture of the projection optical system is NA_1 and the numerical aperture of the illumination optical system determined by the outer diameter of the annular secondary light source is NA_2, the apparatus according to the present invention be designed to the following conditional expression (2):

$$0.45 \leq NA_2/NA_1 \leq 0.8 \qquad \ldots\ldots(2)$$

If the lower limit of this conditional expression (2) is exceeded, the angle of incidence of the light which inclination-illuminates the reticle by annular illumination will become small and the effect of annular illumination according to the present invention can hardly be obtained. Therefore, effecting annular illumination will become meaningless in itself.

If conversely, the upper limit of conditional expression (2) is exceeded, the resolution as a spatial image will be improved, but the depth of focus will be reduced. Further, the contrast at the best focus will be greatly reduced, and this is not preferable.

[0013]

[Embodiments]

Some embodiments of the present invention will hereinafter be described with reference to the drawings.

Figure 1 schematically shows the construction of first embodiment of the present invention, and the first embodiment of the present invention will hereinafter be described in detail with reference to Figure 1.

Light (for example, light of g-line (436 nm), i-line (365 nm) or the like) from a mercury arc lamp 1 is condensed by an elliptical mirror 2 and is converted into a parallel light beam by a collimator lens 4 via a reflecting mirror 3. Thereafter, when the parallel light beam passes through a fly-eye lens 5 (optical integrator) comprised of an aggregate of a plurality of bar-like lens elements, a plurality of light source images are formed on the exit side thereof, and here are formed a plurality of secondary light sources corresponding to the number of the bar-like lens elements constituting the fly-eye lens 5.

[0014]

An aperture stop 6 having an annular transmitting portion is provided at a location whereat the secondary

light sources are formed, and here are formed a plurality of annular light sources.

The aperture stop 6, as shown in Figure 2, is formed by the deposition of light intercepting portions 6b and 6c of chromium or like material so that for example, an annular transmitting portion 6a may be formed on a transparent substrate such as quartz. Alternatively, the aperture stop 6 may be comprised of a circular light intercepting member and a light intercepting member having a circular opening larger than that.

[0015]

When here, the diameter of the light intercepting member 6b of the aperture stop 6 (the inner diameter of the annular transmitting portion 6a) is d_1 and the diameter of the light intercepting member 6c of the aperture stop 6 (the outer diameter of the annular transmitting portion 6a) is d_2 and d_1/d_2 is defined as an annular ratio, the annular ratio of the aperture stop 6 is designed within a range of 1/3 to 2/3.

Now, the lights from the plurality of secondary light sources formed by the aperture stop 6 are condensed by a condenser lens 8 via a reflecting mirror 7 and superposedly uniformly illuminate a circuit pattern 9a on a reticle 9 from an oblique direction. Thereupon, the image of the circuit pattern on the reticle 9 is formed on a wafer 11 by a projection optical system 10. Accordingly, resist applied onto the wafer 11 is sensitized and the image of

the circuit pattern on the reticle 9 is transferred thereto.

[0016]

An aperture stop 10a is provided at the position of the pupil (entrance pupil) of the projection optical system 10, and this aperture stop 10a is provided conjugately with the aperture stop 6.

Figure 3 shows the state of the circular opening portion P of the aperture stop 10a, and as shown, the image I of the annular secondary light source is formed inside the opening portion A of the aperture stop 10a, and the annular ratio of the image I of this secondary light source (the inner diameter D_1 of the image of the secondary light source/the outer diameter D_2 of the image of the secondary light source) is equal to the above-mentioned annular ratio of the aperture stop 6.

[0017]

When here, the diameter of the opening portion of the aperture stop 10a is D_3, the ratio (D_2/D_3) of the outer diameter of the image of the secondary light source to the diameter of the opening portion A of the aperture stop 10a is called a coherence factor, i.e., σ value, and at this time, the image I of the annular secondary light source is formed within the range of the σ value of 0.45 to 0.8, as shown in Figure 3.

When as shown in Figure 1, the reticle side numerical aperture of the projection optical system 10 determined by

a ray R_1 from the most marginal edge of the aperture stop 10a which is parallel to the optical axis Ax is NA_1 (= sin θ_1) and the numerical aperture of the illuminating optical system (1-8) determined by a ray R_2 from the most marginal edge (the outermost diameter) of the aperture stop 6 which is parallel to the optical axis Ax is NA_2 (= sin θ_2), the σ value is also defined by the following equation:

[0018]

$$\sigma = NA_2/NA_1$$

Now, if the aperture of the aperture stop 10a is variably designed to vary the σ value, it is possible to control the depth of focus, resolution, and the like.

Therefore, in the present embodiment, it is possible to achieve further improvement of the depth of focus and resolution since the annular illumination is effected by the disposition of the aperture stop 6. However, an optimum illuminating condition conforming to each of various processes such as a process in which the printing of a minute pattern is required and a process in which a great depth of focus is required can be achieved by varying the aperture A of the aperture stop 10a to vary the σ value.

[0019]

Also, in the foregoing embodiment shown in Figure 1, the aperture stop 6 is fixedly used. However, as shown in Figure 4, a plurality of aperture stops having different annular ratios may be provided along the circumferential

direction of a circular substrate.

In Figure 4, a first group of aperture stops (60b to 60c) having different annular ratios within a range of 1/3 to 2/3 and a second group of aperture stops (60f to 60h) having an outer diameter differing from that of the first group of aperture stops and having different annular ratios within a range of 1/3 2/3 are provided on a transparent circular substrate 60 by the deposition of chromium or the like. Further, a circular aperture stop 60a having the same diameter as the outer diameter of the first group of aperture stops and a circular aperture stop 60e having the same diameter as the outer diameter of the second group of aperture stops are provided on the circular substrate 60.

[0020]

It is possible to control the depth of focus and the resolution, as mentioned above, by properly rotating the above-mentioned aperture stops of the turret type to dispose the aperture stops (60b to 60c, 60f to 60h) having the optimum annular ratio on the exit side of a fly-eye lens 6, so that the optimum annular illumination can be effected under the optimum σ value. Also, if the aperture stops (60a, 60e) also having circular apertures normally are provided on the exit side of the fly-eye lens 6, the exposure by normal illumination can be effected.

[0021]

Further, a mask such as a bar code containing process information, information regarding the required depth of

focus and information regarding the minimum line width to be exposed may be provided on a reticle, and mask detecting means for detecting such mark by use of the reticle may be provided. Thus, on the basis of the information detected through this mark detecting means, a suitable annular ratio for a replaceable aperture stop of the turret type and a suitable σ value may be automatically selected.

[0022]

Next, Figure 5 is a view for showing a schematic construction of the second embodiment according to the present invention. The second embodiment according to the present invention will be described with reference to Figure 5. In Figure 5, members functionally similar to those in the first embodiment of Figure 1 are given the same reference characters.

The difference of the second embodiment from the first embodiment is that instead of the aperture stop 6 provided between the fly-eye lens 5 and the reflecting mirror 7, there are provided a condensing lens 20 and a light guided 21 comprised of a plurality of optical fibers having their entrance sides bundled into a circular shape and having their exit sides bundled into an annular shape, and a number of annular light sources are formed without intercepting a light beam from the fly-eye lens 5.

[0023]

As shown in Figure 6, a circular member 21a for bundling a plurality of fibers is provided at the entrance

end of the light guide 21 and an annular member 21b for bundling the plurality of fibers into an annular shape is provided at the exit end of the light guide.

The ratio of the inner diameter of the exit end of the light guide 21 to the outer diameter of the exit end of the light guide 21, i.e., the annular ratio, is designed so as to be 1/3 to 2/3, and as shown in Figure 3, an annular light source image of which the σ value is of the order of 0.45 to 0.8 is formed at the position of the aperture stop 10a of the projection optical system.

[0024]

By the above-described construction, in the present embodiment, annular illumination can be effected efficiently without intercepting the light from the light source 1 and therefore, not only greater improvements in the depth of focus and resolution can be achieved, but also exposure under a high throughput can be accomplished.

Again in the present embodiment, as described above, means for detecting a mark including various kinds of information on the reticle may be provided and on the basis of the information detected thereby, the optimum diameter of the opening portion of the aperture stop 10a may be set, and annular illumination under an optimum σ value may be effected.

[0025]

Of course, an excimer laser (KrF: 248 nm, ArF: 193 nm, etc.) may be used as the light source of the apparatus

according to the present invention.

[0026]

[Effect of the Invention]

As described above, according to the present invention, it is possible to accomplish the exposure under a resolution higher than that in practical use since a greater depth of focus than that of the prior projection exposure apparatus can be securely obtained. Thereby a more minute pattern than that in the prior projection exposure apparatus can be transferred on the wafer.

[Brief Description of the Drawings]

[Figure 1]

A view schematically showing the construction of a first embodiment of the present invention.

[Figure 2]

A plan view showing the construction of an aperture stop.

[Figure 3]

A view for showing the opening portion of an aperture stop provided at the pupil position of a projection optical system.

[Figure 4]

A view for showing aperture stops for effecting an annular illumination in a turret arrangement.

[Figure 5]

A view for showing a schematic construction of a

second embodiment of the present invention.

[Figure 6]

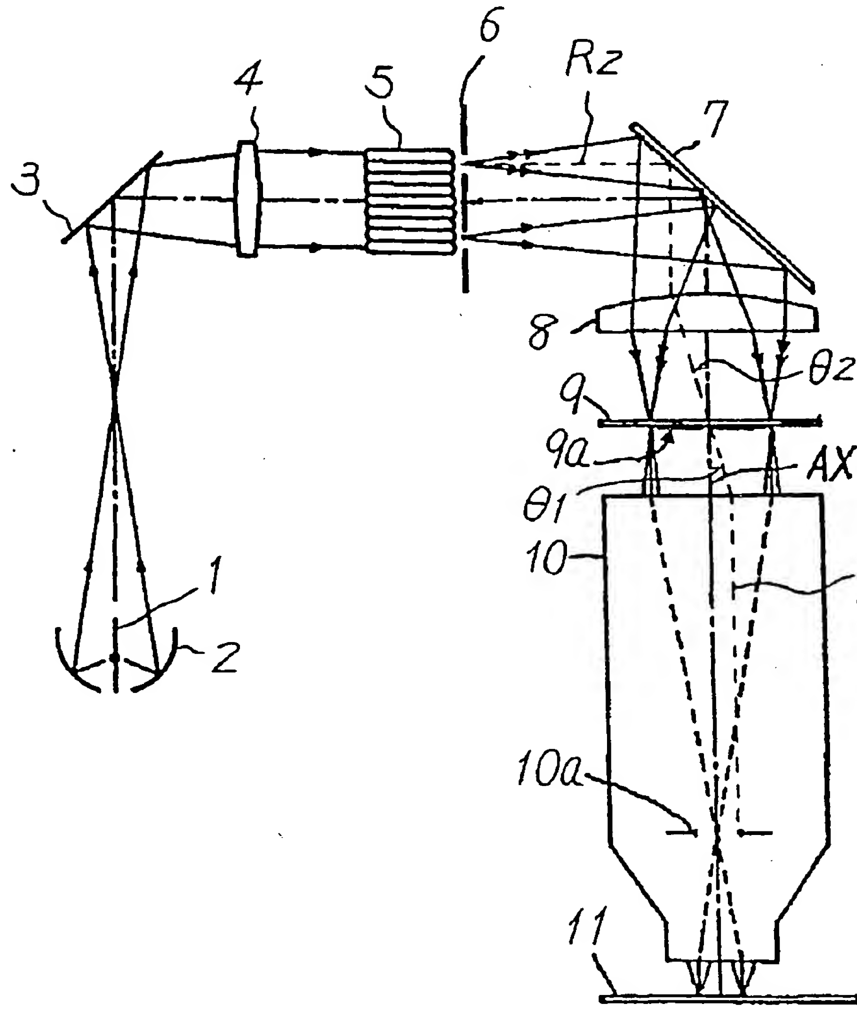
A perspective view for showing a light guide.

[Description of Reference Numerals or Symbols]

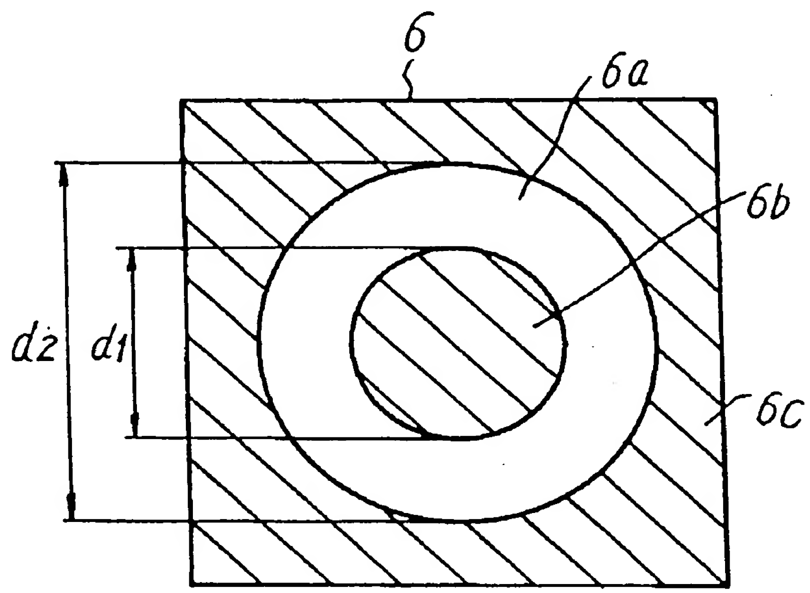
1	Mercury arc lamp
2	Elliptical mirror
3,7	Reflecting mirrors
4	Collimator lens
5	Fly-eye lens
6,10a	Aperture stops
8	Condenser lens
9	Reticle
10	Projection optical system
11	Wafer
21	Condensing lens
22	Light guide

【書類名】　図面　[Name of the Document] Drawings

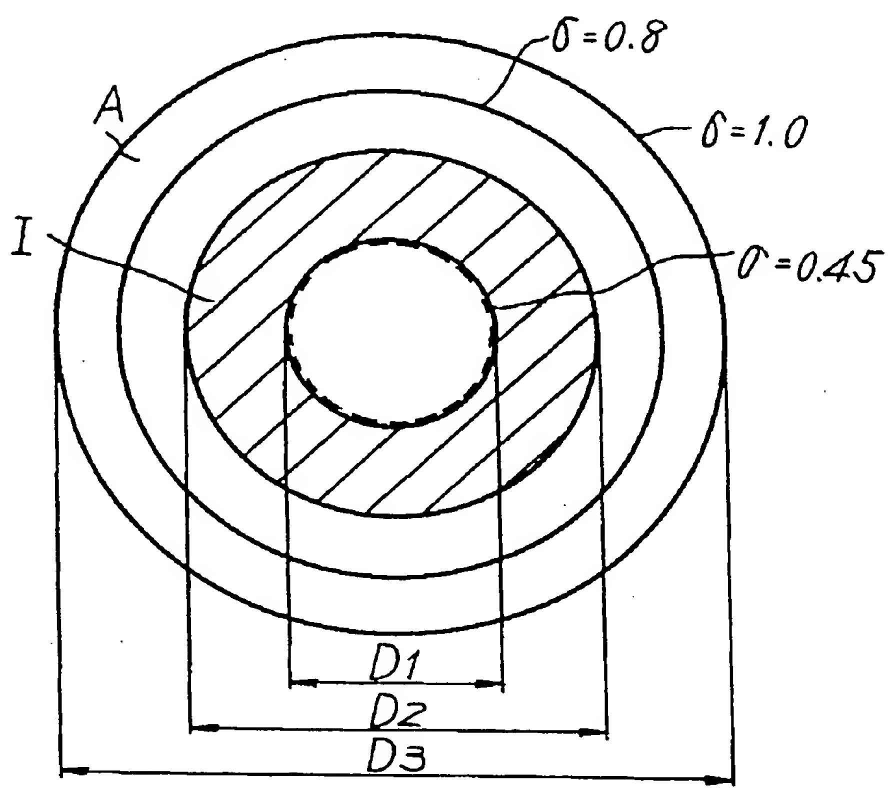
【図１】　Fig. 1



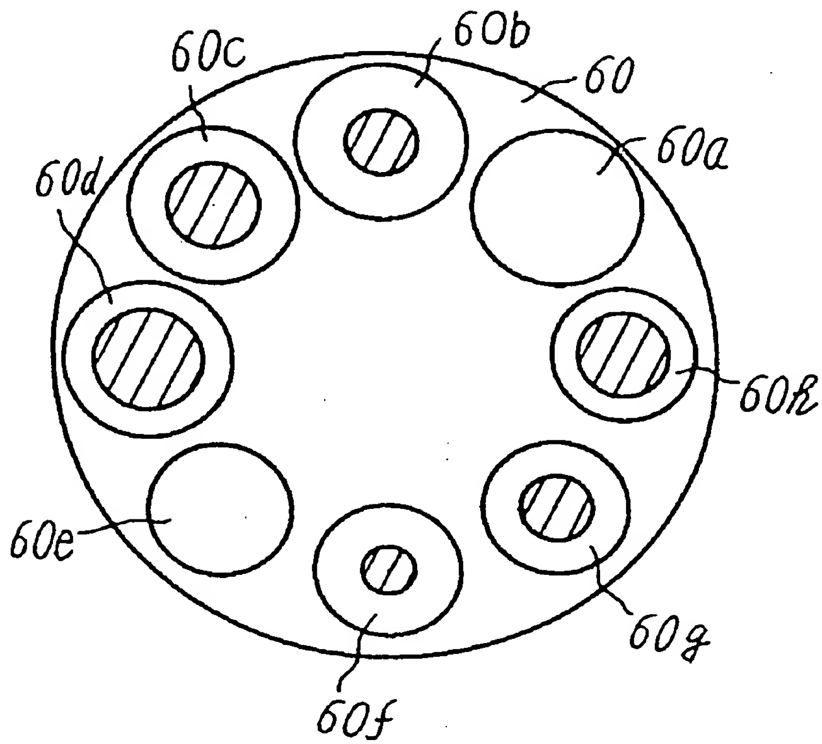
【図２】　Fig. 2



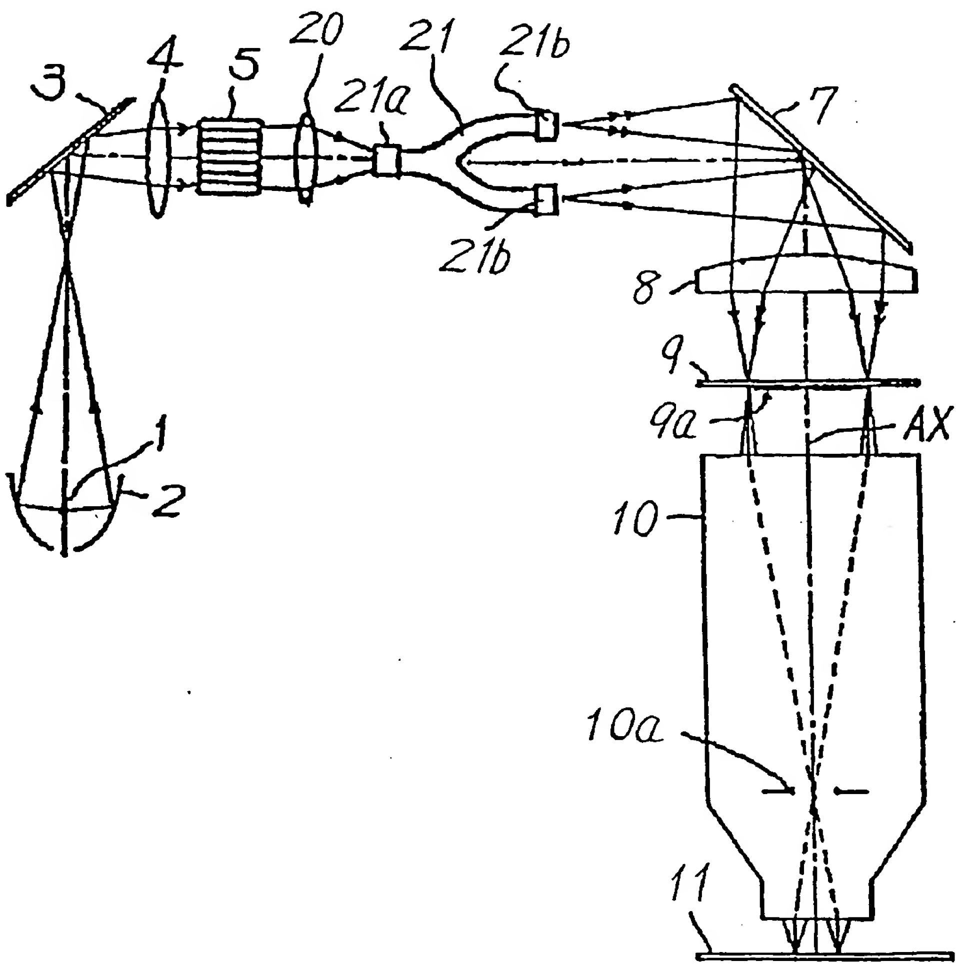
【図３】　Fig. 3



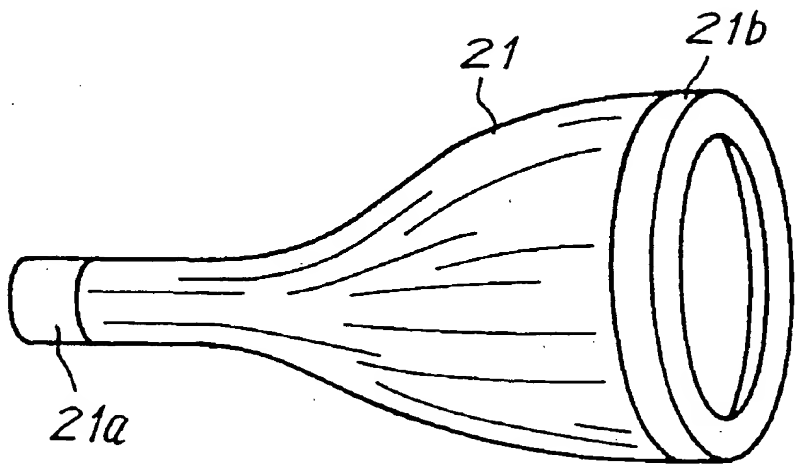
【図４】 Fig 4



【図５】 Fig. 5



【図６】 Fig. 6



[Name of the Document] Abstract

[Abstract]

[Object] An object of the present invention is to provide a projection exposure apparatus in which the depth of focus of a projection optical system is improved, whereby in practical use, a circuit pattern on a reticle can be faithfully transferred onto a wafer with a higher resolution.

[Constitution] There is provided a projection exposure apparatus for projection-exposing a pattern on a projection negative by means of exposure light from an illuminating optical system through a projection optical system, wherein the illuminating optical system includes annular light source forming means for forming an annular secondary light source, and a ratio of d_1/d_2 is within a range of 1/3 to 2/3 where the inner diameter and the outer diameter of this annular light source forming means are d_1 and d_1, respectively.

[Elected Drawing] Figure 1